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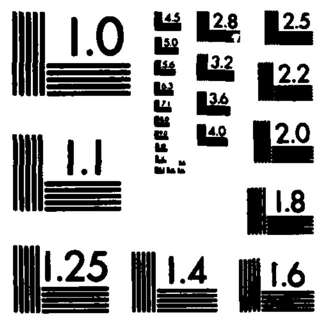

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SYSTEMS PERFORMANCE AND SURVIVABILITY CONSIDERATIONS FOR TACTICAL TARGET RECOGNITION

AD A122431

GILBERT G. KUPERMAN

JULY 1982

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AIR FORCE AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
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AFAMRL-TR-81-60

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
Air Force Aerospace Medical Research Laboratory

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This report develops tactical strike profiles on the basis of the current ground-to-air defensive threat and the capabilities of target acquisition and weapon delivery sensors. Sensor utilization trade-off areas are identified and sensor/display models are presented. A series of nomograms are provided to assist in performing trade-off analyses.

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PREFACE

This report was prepared by the Visual Display Systems Branch, Human Engineering Division, of the Air Force Aerospace Medical Research Laboratory. The research was carried out under Work Unit 71841145, "Display Requirements for Tactical Night Systems" which was monitored by Mr. William N. Kama.

The author acknowledges the advice and assistance of Ms. Kathleen Mazzela Berisford and Ms. Linda Ellison, Systems Research Laboratories, Inc., Dayton, Ohio, in preparing the nomograms presented herein.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

THE THREAT

The threat associated with conducting tactical air operations over enemy territory has evolved to the point where it must now be considered one of the primary factors in mission planning and, indeed, in system development. Based on USAF experience in WW II and Korea, once air superiority had been established, tactical air planners could largely discount the effectiveness of antiaircraft systems (guns) against high speed aircraft. More recently, this situation has changed radically. FM 100-5, *Operations*, points out that: "Since World War II, the range, accuracy, and lethality of air defense weapons has increased dramatically. The antiaircraft weapons of 1945 were guns, some radar controlled, but all limited in range to about 10 kilometers. In contrast, today an air defense complex in a forward divisional area is made up of gun and missile systems covering the battle area forward and behind the area of contact for as much as 40 kilometers."

Crawford (1977) described the effects of the development of more diverse and sophisticated antiair weapon systems by contrasting U.S. experiences in Southeast Asia with those encountered by the Israeli Air Force shortly thereafter, "During the closing days of the war in Southeast Asia, U.S. tactical aircraft were able to penetrate the relatively heavily defended air space of North Vietnam at medium altitudes almost at will because of the limited diversity of the surface-to-air defense systems and the effectiveness of the fighter-carried ECM pods and other electronic warfare equipment. During the 1973 Middle East War, the Israeli Air Force (IAF) was forced to change tactics due to the proliferation, diversity, and redundancy of Arab surface-to-air defenses." Before the 1973 conflict, the primary Arab air defense systems were the SA-2 and -3. According to Rubenstein and Goldman (1978), these missile systems were not serious threats. The SA-2 was a totally high altitude threat and "a pilot simply has to fly below the minimum effective altitude of the missile." The IAF's ability to nullify the SA-3 was based on both equipment and tactics in that "part of the answer was in effective ECM ... to jam the frequency used by the SA-3's radar [and] the other part of the reply was to fly lower still." By late 1973, a totally different air defense situation obtained. Again, according to Rubenstein and Goldman, "by combining these weapons--the SAM-2, -3, -6 and -7s and ZSUs [ZSU-23-4 and ZSU-57-2]--the Arabs were able to construct zones of antiaircraft defense that were denser, more sophisticated, and more nearly impenetrable than ever before encountered, Vietnam included." They further pointed out that the ZSU-23-4 and SA-7 were "most effective at very low altitudes" and that, as to the SA-6, the IAF "had not yet (1973) discovered ... how to jam its radar guidance systems." Major General Herzog (1975), twice former director of Israeli Military Intelligence, described the combined weapon system air defense capability that the IAF had to contend with. He pointed out that "the mobile SAM 6, with an effective range 22,000 meters, fits into a comprehensive pattern provided by the comparatively static SAM 2 (with a range of 50,000 meters) and the more mobile SAM 3 (30,000 meters)." He further noted that "each of these weapons possesses different electronic guidance characteristics, which complicates the application of electronic countermeasures." Rubenstein and Goldman summarized the impact on tactical aircraft flight profiles by stating that "no altitude would be safe, but the lower altitudes, at which the all-important air support and flak suppression missions had to be flown, would be nightmarish." Crawford concurred with this assessment by stating that "the standard low level run-in with a pop-up for weapon delivery in the classical close air support (CAS) role had been abandoned due to the severity of the defenses and resulting high attrition." She also described the partially successful, but more survivable, tactic in which "attacks were then directed toward targets not in contact generally using toss or loft bombing, the accuracy of which degraded as avionics maintenance became infrequent or impossible."

A critical implication of the encountering of the modern air defense, described above, was the required change in air power utilization. According to Rasmussen (1978), the IAF was unable to execute its priority mission of offensive counterair operations, and instead, "the highest priority was necessarily assigned to defensive direct support operations--specifically, stopping the armored thrusts." Because many of the antiair weapons were mobile and integrated into these attacking formations, the IAF was forced to accept direct confrontation. Rasmussen points out that, while the 1973 Arab air defenses were "the most lethal seen in action to date," the numbers, types, and dispositions "of similar defenses on the front in Central Europe may be even more deadly."

Against this background, several points can be established that relate directly to tactical air operations. Priority targets will be armored vehicles either already engaged with friendly defenses or entering the attack. Colocated with the armored units will be very effective, mobile air defenses (particularly the SA-6 and ZSU-23-4). Conventional weapon delivery tactics may well result in unacceptable levels of friendly air force losses. By implication, countermeasures, weapons, and tactics must be developed to enhance survivability. Two such areas of emphasis are of interest to this effort, terrain avoidance/terrain following (TA/TF) penetration and standoff weapon delivery.

NEAR TERM USAF SYSTEMS

Several weapon systems are entering or planned for the USAF inventory which are intended to be effective air-to-surface resources. The A-10 aircraft is a close support weapon system, employing the GAU-8 30 mm, internal, seven barrel gun and television-guided Maverick missile AGM-65. The F-4 inventory is being equipped with the PAVE TACK FLIR pod to enhance its effective delivery of infrared-guided Maverick missiles. The F-16 airfleet is also capable of delivery of the AGM-65 and is typically associated with interdiction missions in addition to its primary air-to-air role. A new program, LANTIRN, (Low Altitude Navigation Targeting Infrared for Night), is intended to provide both the A-10 and F-16 fleets with enhanced capabilities through the addition of FLIR sensors, video HUDs, automated target recognition processors, and laser designation/ranging subsystems. As can be seen, developing systems are oriented to improvements in the night attack capability. The current capability is more heavily daylight oriented.

The recently completed Tactical Aircraft Survivability Evaluation (TASVAL) provided some insight into the possible effectiveness of multiple aircraft (both numbers and types) in daylight, air-to-surface attack. TASVAL was a highly instrumented and extensive field exercise designed to "reduce uncertainties associated with decisions on weapon system acquisition, force structure, and force mix" (Hartman, 1979). The TASVAL exercises were based on two scenarios: Red Force in the attack with a 4:1, or higher, ground force superiority or Red Force in the hasty defense. Of interest to this paper, th Blue Force mix of Air Force A-10 and Army scout and attack helicopters was employed against enemy armor, tanks and command vehicles, and mobile antiair weapons including simulated SA-7, SA-8, SA-9, and ZSU-23-4 weapon systems. Although TASVAL was a daylight field trial, the weapons, flight profiles and tactics, and engagement ranges are still credible when extrapolated to night operations, although the specific tactics used in TASVAL close-air-support missions might well require modification for application in battlefield/interdiction missions. Hartman reported that: "the attack helicopter teams engaged targets by operating from the surface to treetop level, and the A-10s operated above treetop level. The A-10s also used the attack helicopters as visual cues, since they operated approximately 3,000 m from the target area, faced the threat, and were visible to the ingressing fighters. Upon moving into their battle positions, the attack helicopters operated from protected positions afforded by terrain features and vegetation. They would rise up and/or move horizontally to unmask, acquire targets, engage targets, and remask." Hartman stressed mobility in that "helicopters engaged one or more targets at each unmasking, depending on received enemy fire and threat air defense activity. They would move to alternate firing positions to preclude repeated exposure from the same position." Table 1 summarizes the TASVAL target acquisition and weapon delivery data.

TABLE 1. WEAPONS DELIVERY RANGES

Platform	Weapon	Acquisition/Pop-up Range	Attack Range
AH-15	TOW	3.0 km	3.0 km
	20 mm	3.0 km	3.0 km
A-10	E.O. Maverick	2.8-5.6 km	1.4-3.7 km
	GAU-8	1.9-2.8 km	0.9-1.9 km

DEVELOPING TACTICS AND SENSORS

The A-10 operational squadrons currently being deployed in Europe are assigned a CAS mission along the NATO-Warsaw Pact border running north from Switzerland. They are equipped with the PAVE PENNY passive laser seeker system and are to be refitted with inertial navigation systems, according to Brown (1979).

He described the emphasis on terrain familiarization being carried out. "Pilots . . . will be assigned sectors along the frontier in which they will learn the terrain, roads, and other geographical aspects in great detail." He also gave some insight into the A-10 CAS concept of operation, reporting that "sectors will be 75-100 miles long and possibly 20 miles deep, and pilots will be able to operate over these sectors without the use of maps or other navigation aids and with minimal radio communication."

The interdiction mission, directed at enemy elements in the second echelon (or deeper) of the enemy force places greater requirement on autonomous operation. In describing the interdiction profile, Hilgendorf et al. (1979) projected "the tactics for the F-16 in an air-to-ground scenario in a high threat environment to employ [high-speed], low-altitude penetration to a prebriefed way point, a pop-up maneuver to gain line of sight with a fixed target, and a single weapon delivery pass. Target reattacks are not planned. Ingress and egress will include accurate steers [i.e., heading changes] to preplanned checkpoints that have been minimized for time over unfriendly territory." They also repeated the recommendation of the Tactical Air Command Single Seat Attack Working Group for an automatic TA/TF. The LANTIRN Statement of Work addreses "self-contained low-level navigation and precision attack missions" and requires that "the navigation function will provide the pilot with WFOV [wide field of view] FLIR video and steering cues" on a "video raster head up display."

Paskin (1979) referred to the results of a large scale simulation program using qualified Tactical Air Command pilots as subjects when he described "the requirement for a 1:1 FLIR WFOV to HUD FOV ratio and a 4:1 FLIR WFOV to NFOV (narrow field of view) ratio." The WFOV FLIR, approximately 20 degrees, was used as an aid to TA flight and for target area location. The FLIR's NFOV was employed for target recognition and as an adjoint in weapon delivery. FLIR sensors are to be exploited for both TA flight and target acquisition. They are passive sensors and offer no emissions for the air defenses to acquire or lock onto. Further, they afford the pilot or navigator with out-of-cockpit images under the visually-degraded conditions of night, adverse weather, and battlefield smoke.

TRADE-OFF AREAS

SENSOR FOV

The FLIR used in the Electro-Optical Viewing System on the B-52 G/H by the Strategic Air Command has a WFOV of about 25 degrees and a 4:1 zoom. The PAVE TACK FLIR has a WFOV of about 12 by 10 degrees and a 4:1 zoom. It is probable that advanced FLIRs for target acquisition and weapon delivery will exhibit WFOVs of 10 degrees or less.

Typically, the FOV of an imaging sensor is not a square. The vertical angular dimension of the FOV is usually three-fourths of the horizontal angular dimension. Multiple detector sensors, composed of lineal or areal detector arrays, and the scan conversion required to produce a two-dimensional image of the ground scene may yield FOVs which are not in this 3:4 aspect ratio.

A narrow FOV sensor offers a more favorable display scale at longer range. It has the disadvantage of making search more difficult because a small area of the ground is covered by the FOV (and, hence, is available for display). Further, the time during which a ground point (target) remains within the displayed FOV is minimized.

A wide FOV is most desirable for the navigation and TA flight tasks because of the need for area coverage. Vertical information is needed for terrain clearance, and horizontal information is required for heading changes and waypoint acquisition.

To some extent, the sensor zoom capability can reconcile the conflicting FOV requirements. It appears realistic to posit a system having, for example, a 32-degree FOV for high speed TA penetration and target search/detection, and a 4-degree FOV for a standoff target acquisition and weapon delivery. The resultant 8:1 zoom might well imply the need for two sensors because of the design and fabrication constraints inherent in infrared optical technology. It would almost certainly mandate two display modes (or two displays) since 1:1 magnification is mandated for terrain avoidance flight while electronic magnification, coupled with zoom capabilities, may be necessary to display all the sensed information to an operator performing a target recognition task.

TERRAIN MASKING

The object of effective terrain use is to enhance survivability by denying enemy air defenses line of sight (visual or radar) to an ingressing aircraft. This means flying through the saddles between adjacent hills and avoiding the altitude (above ground level) "ballooning" attendent to ridge crossings. The altitude that must be maintained to make most effective use of terrain masking is a function of the average terrain slope angle and the ground range to the ground-based observer:

$$\text{Altitude} = \text{Ground Range} \times \tan(\text{Slope Angle})$$

Burge and Lind (1977) produced probablistic data of an unobstructed line of sight existing between an aircraft and a ground point for 12 types of terrain (and vegetation) combination.

For either visual or sensor-aided target acquisition, a clear line of sight must exist between the strike aircraft and the ground target. Since it is reasonable to assume air defenses at the target, either mobile or fixed, the pop-up maneuver required to achieve target unmasking should be kept to a minimum altitude and made as close to the target as is practical to minimize exposure time; the minimum altitude criterion also results in a minimum range, based on the terrain slope.

The minimum range and altitude desired for survivability can make the operator's task more difficult by minimizing the time available to him in which to acquire the target and initiate an attack. Wessely (1978) concluded "that terrain masking is a major limiting factor in long range target acquisition."

RESOLUTION

In its simplest sense, resolution refers to target information obtained by the sensor *and* made available to the observer. Properly, then, a consideration of resolution should be divided into two parts, sensor sampling of the target and observer sampling of the displayed target image.

The amount of information that must be obtained about the target depends strongly on the task to be carried out. Intuitively, an observer would need significantly more information to decide whether an object were a tank, truck, or armored personnel carrier (i.e., recognition) than to simply decide that an object of interest was present in the display scene (i.e., detection). This relationship between required resolution and task type has been borne out through empiric studies. Johnson (1958) reported that 8.0 (plus/minus twenty percent) TV lines were required across a target's critical dimension to support recognition. Ratches et al. (1975) provided a table for the correct recognition of Army vehicles as a function of resolution (e.g., 8 TV lines across the target's critical dimension would support correct recognition between 50 and 80 percent of the time). Bailey (1970, 1972) adopted a slightly more conservative value than that given by Johnson and which agrees with the table in Ratches et al. Bailey's prediction for 90 percent correct recognition requires 10 TV lines (while Johnson's value of 8 TV lines would result in correct recognition in a little over 60 percent of the attempts according to Bailey's model).

The second usage of resolution involves the transfer of information from the display to the observer. (It is assumed, for purposes of simplicity, that the display is sufficiently well-matched to the sensor that it introduces essentially no loss of information.) The value often used to describe the displayed target image is the angle subtended by it on the display. This angle is a function of both the displayed target size and the observer-to-display viewing distance. The subtended angle is found by:

$$\text{Subtended Angle} = 2 \arctan\left(\frac{\text{Target Size on Display}/2}{\text{Viewing Distance}}\right)$$

Bailey (1970) drew on Steedman and Baker's 1960 study to include the required target angular subtense in his recognition model. He found that the target should subtend about 20 minutes of arc for 90 percent correct response to be supported. Task (1979) described a viewing situation to be "vision-limited" if the angular subtense of the display resolution element, i.e., the TV line, "is much smaller than the angular resolution limit of the eye (1 to 1-1/2 minutes of arc)." This would require the 10 TV lines needed for target recognition to subtend an angle of 10 to 15 minutes of arc on the display. Erickson and Hemingway (1970) reported just this case in the results of a study which showed that the recognition of military vehicles required at least 10 lines on the target and a subtended angle of at least 14 minutes of arc on the display.

The trade-off area associated with resolution can be approached in terms of both the sensor and display. If a long standoff distance is required, then a small sensor field of view may be needed, for a given line rate, to obtain sufficient lines on target, or a higher line rate sensor may be employed. For a fixed display size, the higher line rate results in a smaller TV line dimension. The observer may move closer to the display or a larger display may be needed.

TARGET SEARCH

If the target is not precisely prelocated or the aircraft navigation system is less than perfect, or both, some target search will be required. Because narrow FOV sensors acquire and display reduced ground coverage, they make the search task more difficult to perform. Large FOV sensors cover more ground but must be used at closer ranges to achieve the desired number of lines on target. Target search, particularly with small FOV sensors, is poorly documented in the operator performance literature. Wessely (1978) pointed out that "the crucial part of the target acquisition problem is the performance of the observer and it must be immediately admitted that we have very little understanding of how an observer actually searches for a target in clutter."

SYSTEM MODELING

Erickson (1978) provided an equation to assist in performing trade-off, or other, sensor/system analyses. His model is as follows:

"The number of lines, ℓ, across a target of *projected* height, h, is given by

$$\ell = \frac{2\,N \arctan\left(\dfrac{h}{2R}\right)}{(FOV)}$$

where

- h = projected target height,
- N = total actual line number of the system
- R = range to the target, and
- FOV = field of view of the sensor

Strictly speaking, N has meaning only in terms of the vertical (field of view) dimension of the display (sensor). CRT scan lines, as on the face of a TV monitor, are written individually. Each line contains a continuously varied signal. Thus, video-forming sensors sample the real world with discrete scan lines in the vertical dimension and each scan line samples the real world continuously in the horizontal dimension. A portion of the time available for writing sensor scan lines (on the display) is taken up to accomplish vertical retrace and so a 525 line system exploits approximately 487 actual lines, an 875 line system exploits approximately 810 actual lines, etc. The sensor and display are conventionally designed so that the equivalent horizontal sample dimension (based on the separation of closely spaced objects, for example) is equal to the vertical line width. Thus, considering the normal 3:4 aspect ratio of vertical to horizontal field-of-view dimensions, a 525 line rate video system has 487 actual vertical lines and (4/3) (487) or approximately 650 equivalent horizontal TV lines. It is often convenient to treat the TV lines in terms of the angle of the field of view that is made up by them and vice versa. Thus, for a 20-degree FOV, 525 line sensor, a target covered by 8 scan lines would subtend approximately 18 minutes of arc in the sensor's FOV.

The "projected target height" used by Erickson refers to the apparent target dimension perpendicular to the boresight of the sensor's FOV. For low-altitude flight and small sensor depression angles, the "projected target height" will closely approximate the true target height. It is often desirable to employ Johnson's critical target dimensions (i.e., the minimum projected target dimension) in Erickson's formula to perform trade-off analyses between the line requirement for recognition and the range at which this requirement can be achieved.

Task (1979) also presented a model for use in performing trade-off analyses. His assumptions were that an imaging sensor system might be display limited (too few TV lines) or might be vision limited (too small a display) but that the cases intermediate to these extremes were also of interest. He based his model on the parameter % D, the percent of the display that the target must occupy for recognition to occur. For the general case, he proposed:

$$\%D = \left(\frac{O_T}{O_D} + \frac{N_T}{N_D}\right)100$$

where

N_T = number of resolution elements required to recognize the target along one dimension

N_D = number of resolution elements across one dimension of the display

O_T = required angular target size for recognition

O_D = angular size of the display with respect to viewer

Task points out that O_T was the product of N_T and the limiting visual acuity of the observer (O_V). In applying this model, he used a value of 1.5 minutes of arc for O_V and provided a procedure for estimating N_D as "the minimum number of samples required to resolve the spatial frequency at which the display MTF (Modulation Transfer Function) drops to 3-1/2 percent."

Erickson's model emphasizes the sensor and the sensor-to-target imaging geometry. Task emphasizes the display-observer interface. Used jointly, they provide tools for analyzing the total geometric imaging system to predict operator performance. Task uses a minimum modulation contrast in estimating the useful resolution limit of the display but neither model treats target contrast directly. This parameter is often treated, for FLIR sensors, through the minimum resolvable temperature (MRT) curve. The MRT is a sensor describing function derived against an engineering target. The target consists of four bars separated by spaces equal to the bar width. The bar length is 7 times the bar width, resulting in an overall square pattern. (The similarity to the Johnson criterion for recognition is obvious and apparently intentional). Such patterns, at different bar widths, are imaged and observers are required to report whether the pattern is judged to be resolved. At each bar width, the temperature of the pattern is varied with respect to that of the background, supporting the collection of threshold (50 percent response) data of the required temperture differences as a function of spatial frequency (i.e., bar width at a fixed imaging distance). These data can be used to assure the modeler that sufficient contrast (temperature difference) exists to support recognition. Temperature differences in the range 3 to 6 degrees Kelvin are typical in representing tactical vehicles. Sufficient contrast is assured since Johnson noted that his resolution requirements were "independent of contrast... as long as the contrast in the resolution chart (i.e., MRT pattern) was the same as the contrast in the complex target (i.e., tactical vehicle)." Self, quoted in Biberman (1973), provided additional assurance by observing that "contrast variation appears to have little effect as long as very low contrasts are not involved."

NOMOGRAMS

Nomograms are graphic aids which are intended to replace frequently repeated numeric calculations. Generally, the user graphically enters the value of an independent variable as a projection upward from the abscissa, locates the intercept of that projection on one of the possibly several curves within the figure, and then projects that intercept laterally to the ordinate and reads the numerical value of the dependent variable from that scale.

Figure 1 depicts the sensor/target imaging geometry. It also serves to define a number of the variables used in the nomograms which follow. The equations used in creating the nomograms follow the parameters of Erickson's (1978) model, together with terms representative of Johnson's (1956) recognition criterion and Steedman and Baker's (1960) subtended angle requirement.

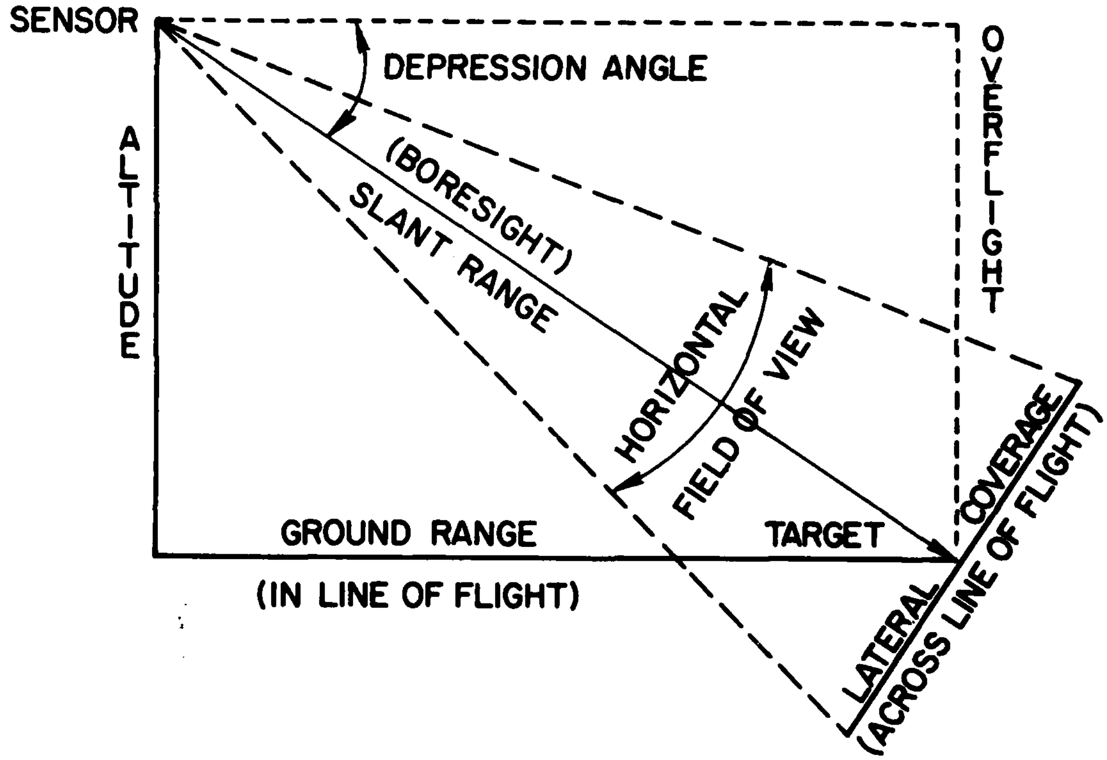

Figure 1. Sensor/Target Imaging Geometry

SLANT RANGE

Slant range is defined as the distance between the sensor and target, measured along the optical axis of the sensor. Slant range is a function of the sensor's (i.e., platform's) height (altitude) above the target plane (a "flat earth" is assumed) and the depression angle of the sensor's bore sight to the target. (See Figure 2.)

Example:	Altitude	=	1000 feet
	Depression Angle	=	7 degrees
			8200 feet

(Figure 2A is also a Slant Range Nomogram, but has expanded scales for altitudes below 1000 feet.)

The Slant Range Nomogram can also be used to study target unmasking. The example used might come about because of a requirement that the altitude not exceed 1000 feet and the information (from, for example, Burge and Lind, 1977) that the terrain masking angle in the vicinity of the target was 7 degrees. The Slant Range, then, would be the maximum slant range at which a clear line of sight could be achieved to the target. *The Slant Range to near edge of* the sensor "footprint" can be found with this nomogram by using the quantity (Depression Angle + 1/2 Sensor Vertical FOV); the Slant Range to the far edge of the "footprint" can be found by using (Depression Angle - 1/2 Sensor Vertical FOV).

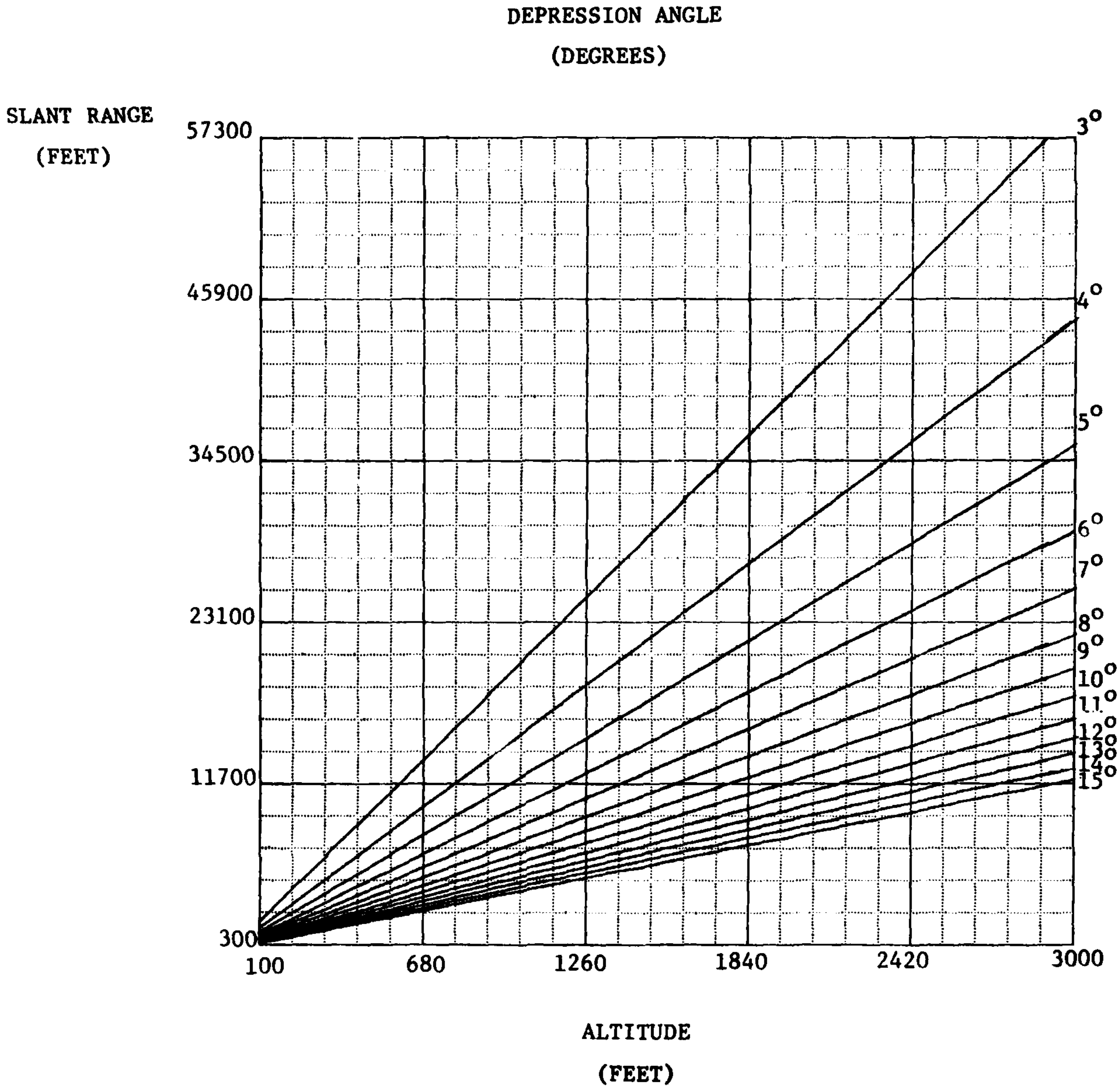

Figure 2. Slant Range Nomogram

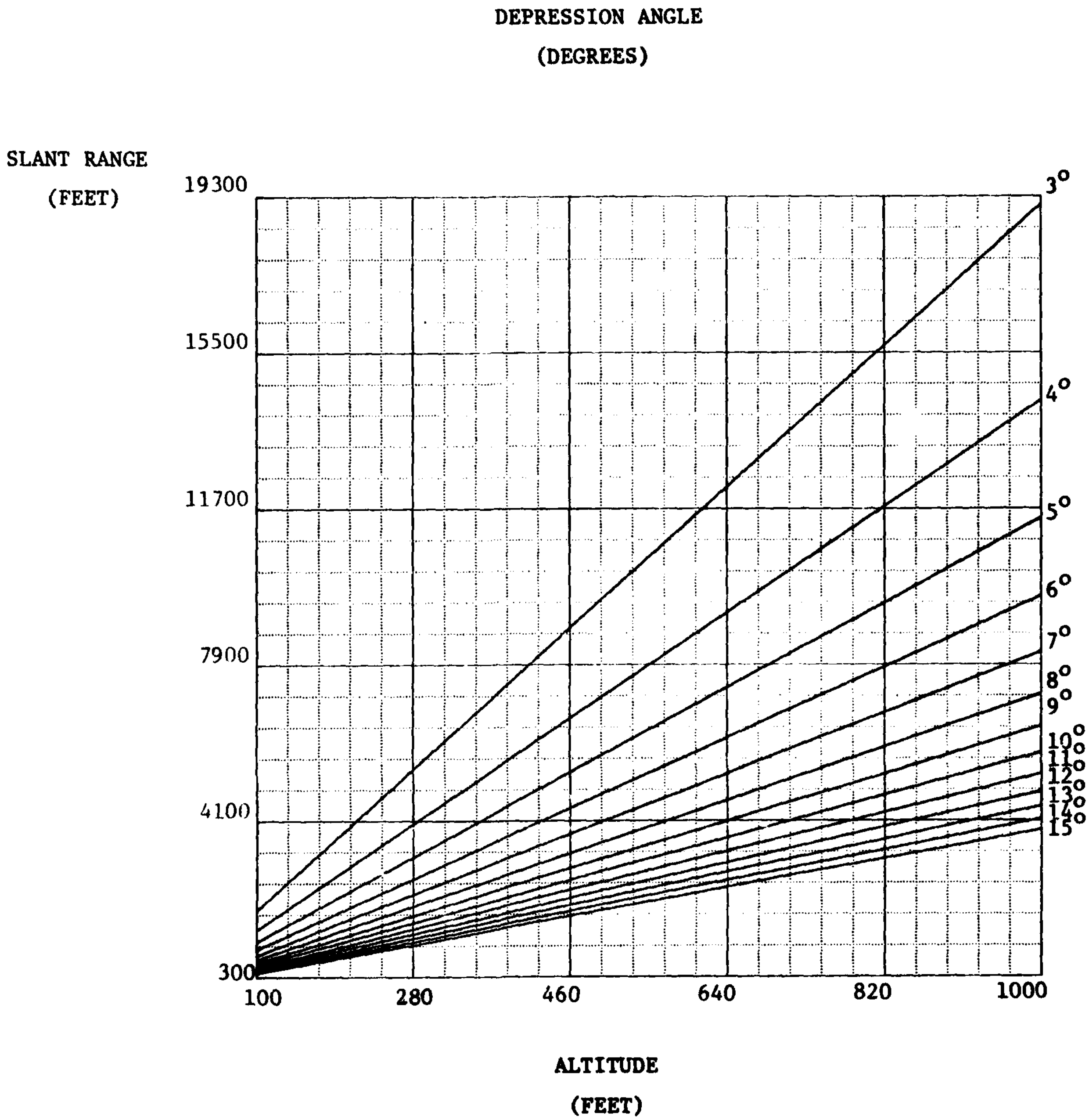

Figure 2A. Slant Range Nomogram--Expanded Scale

GROUND RANGE

This distance, in the plane of the target, is that between the ground point directly beneath the aircraft and the target. It is the third side of the triangle which also contains Altitude and Slant Range. (See Figure 3.)

Example:	Slant Range	=	8200 feet
	Depression Angle	=	7 degrees
	Answer:		8100 feet

TIME TO TARGET

Time to target is expressed as the number of seconds of level flight until the aircraft overflies the target. (See Figure 4.)

Example:	Ground Range	=	8100 feet
	Velocity	=	500 knots
	Answer:		9.6 seconds

(If the velocity is known in feet/second, divide by 1.69 to obtain knots.)

This nomogram may also be used in a geometry in which the strike aircraft is diving at the target at constant velocity. The slant range is used instead of the ground range.

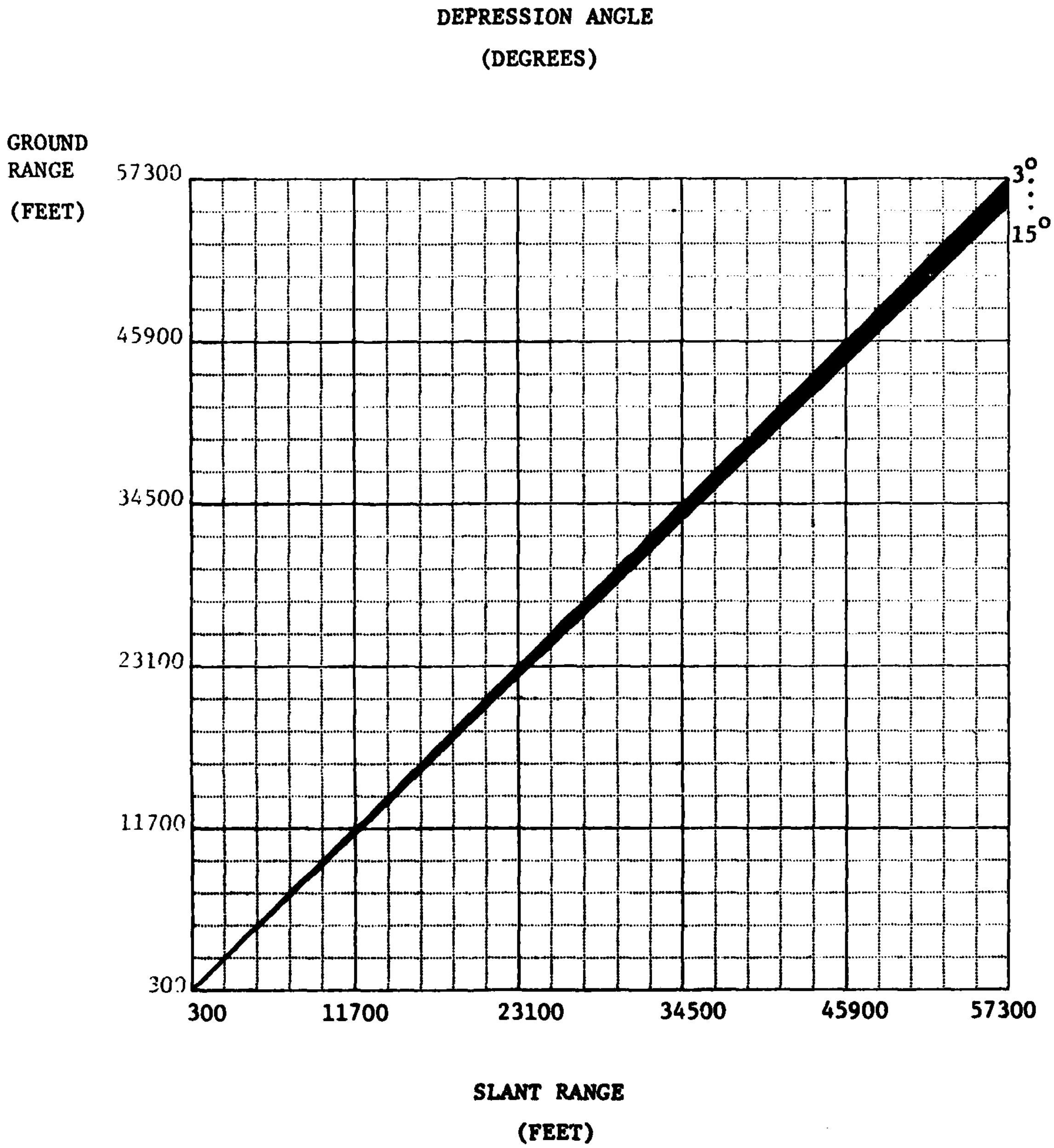

Figure 3. Ground Range Nomogram

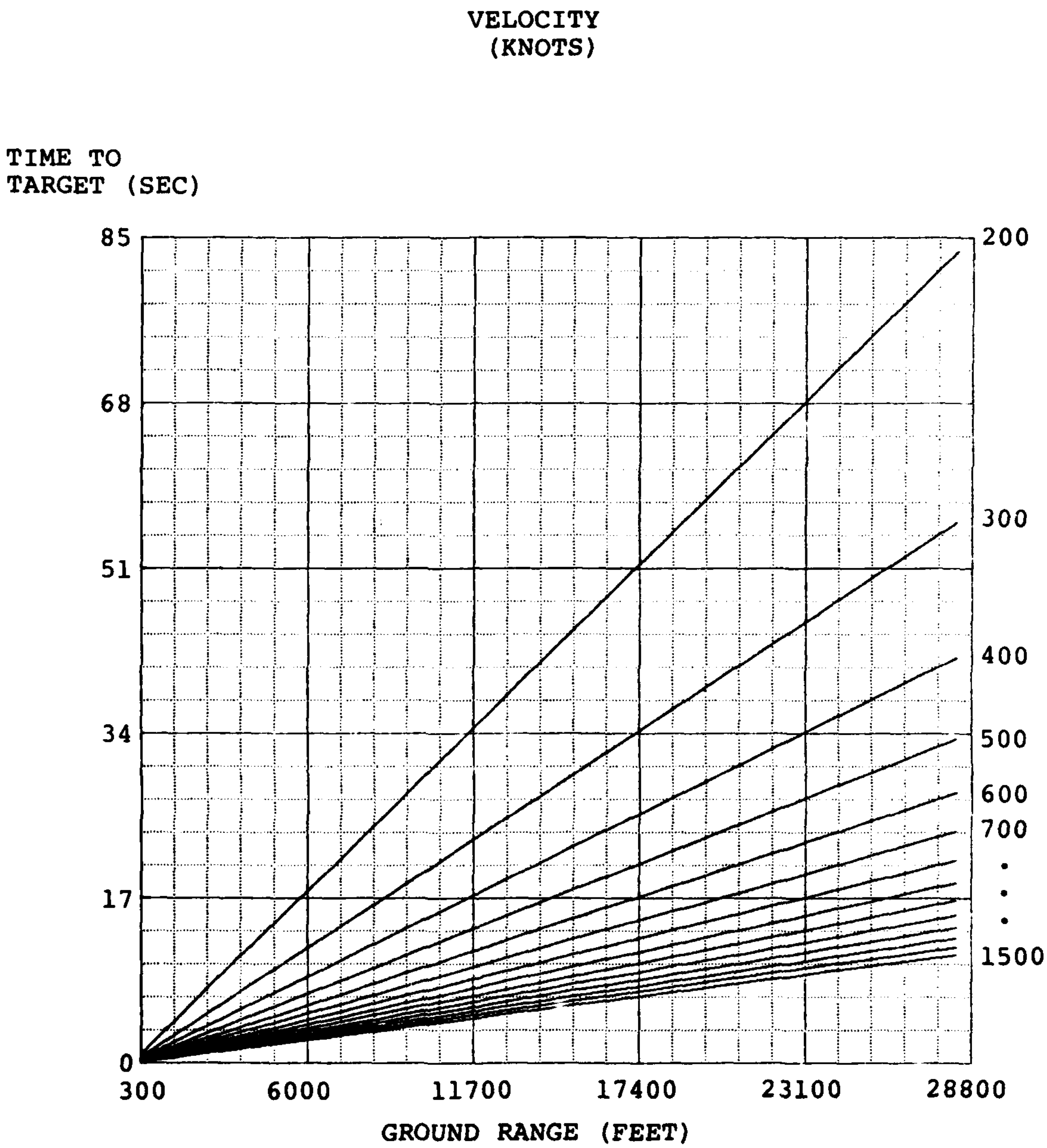

Figure 4. Time to Target Overflight Nomogram

LATERAL COVERAGE

Lateral coverage is the width of the ground plane imaged at the center of the sensor's FOV, perpendicular to the projected track of the aircraft. (See Figure 5.)

Example:	Slant Range	=	8200 feet
	Sensor Horizontal FOV	=	10 degrees
	Answer:		1400 feet

The ground coverage "footprint" can be computed by using the slant ranges to the near and far edges to determine the corresponding lateral coverage.

ANGLE SUBTENDED BY TARGET AT THE SENSOR

This is the angle formed in the sensor's FOV by the projected target dimension in a plane containing the target and perpendicular to the sensor's boresight. Figure 6 shows this geometry. The minimum target dimension is often conservatively used for the projected dimension. Alternatively, the average of the target's length, width, and height dimensions may be used in an attempt to employ a value independent of viewing aspect. (See Figure 7.)

Example:	Slant Range	=	8200 feet
	Target Projected Dimension	=	10 feet
	Answer:		.070 degrees

LINES ON TARGET

This is simply the number of TV lines in the sensor's FOV that are placed across the critical dimension of the target. Since the target projection is perpendicular to the sensor's boresight, the number of lines accross the target is the ratio of the subtended angle (from Figure 7) to the total

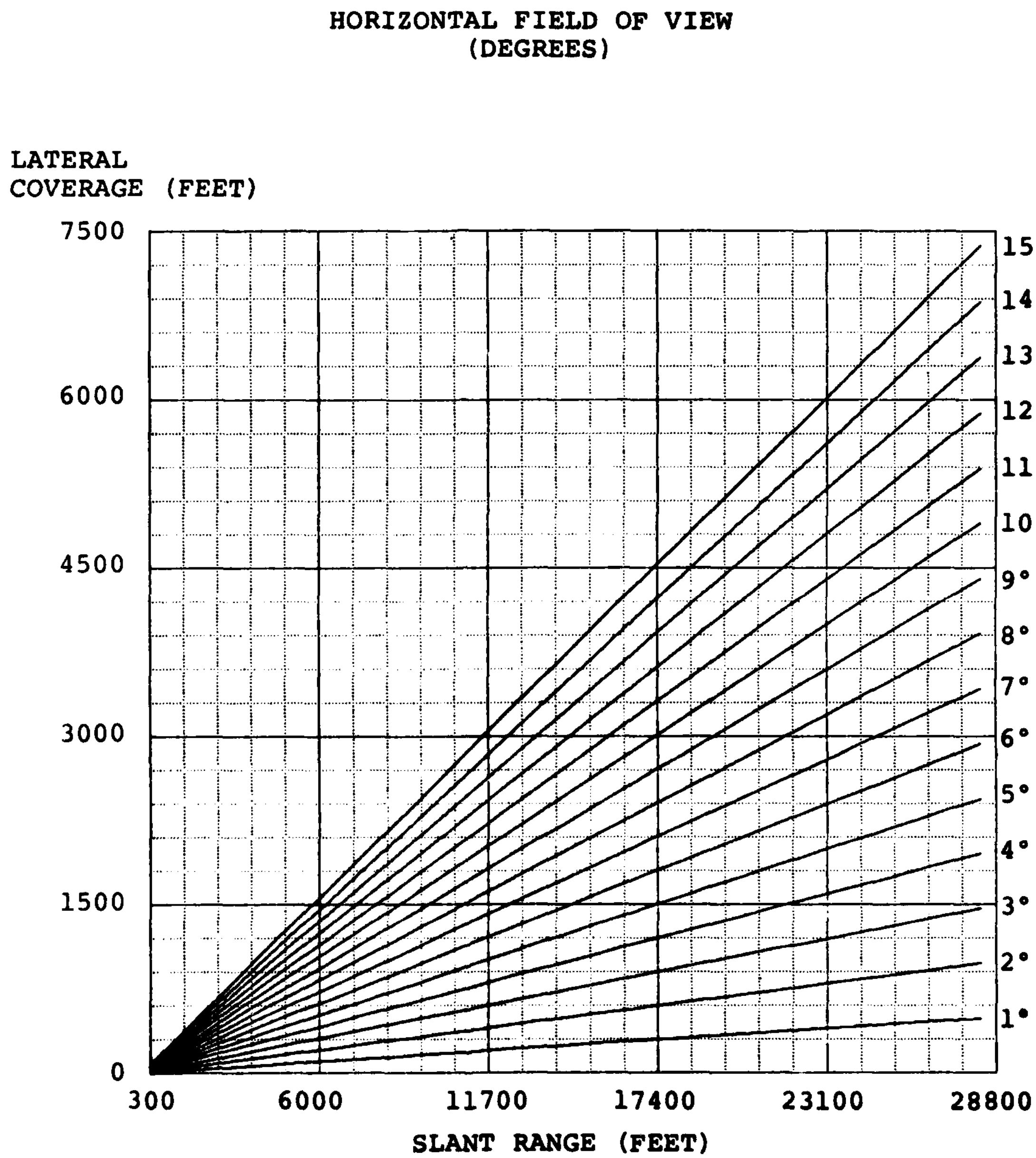

Figure 5. Lateral Coverage Nomogram

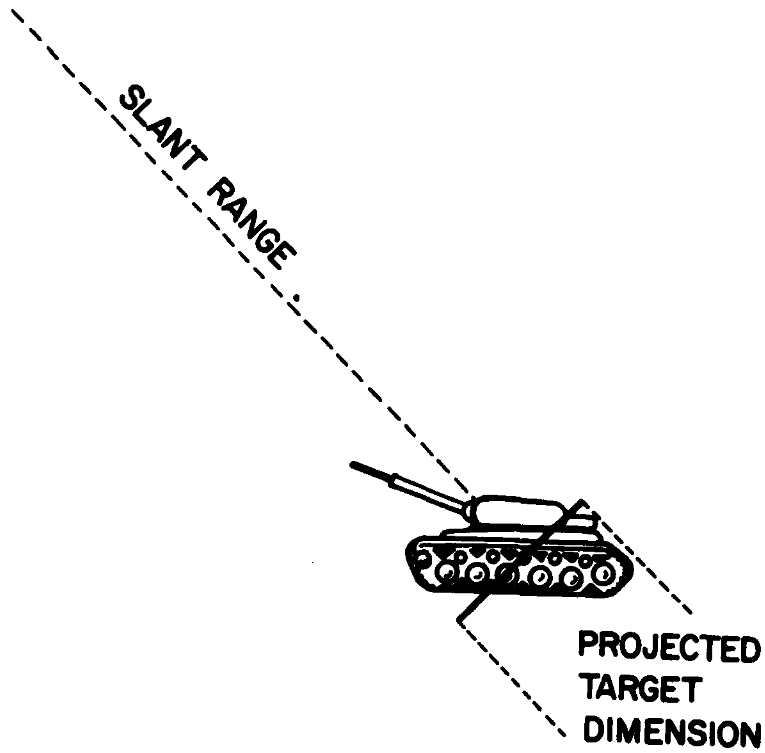

Figure 6. Projected Target Dimension

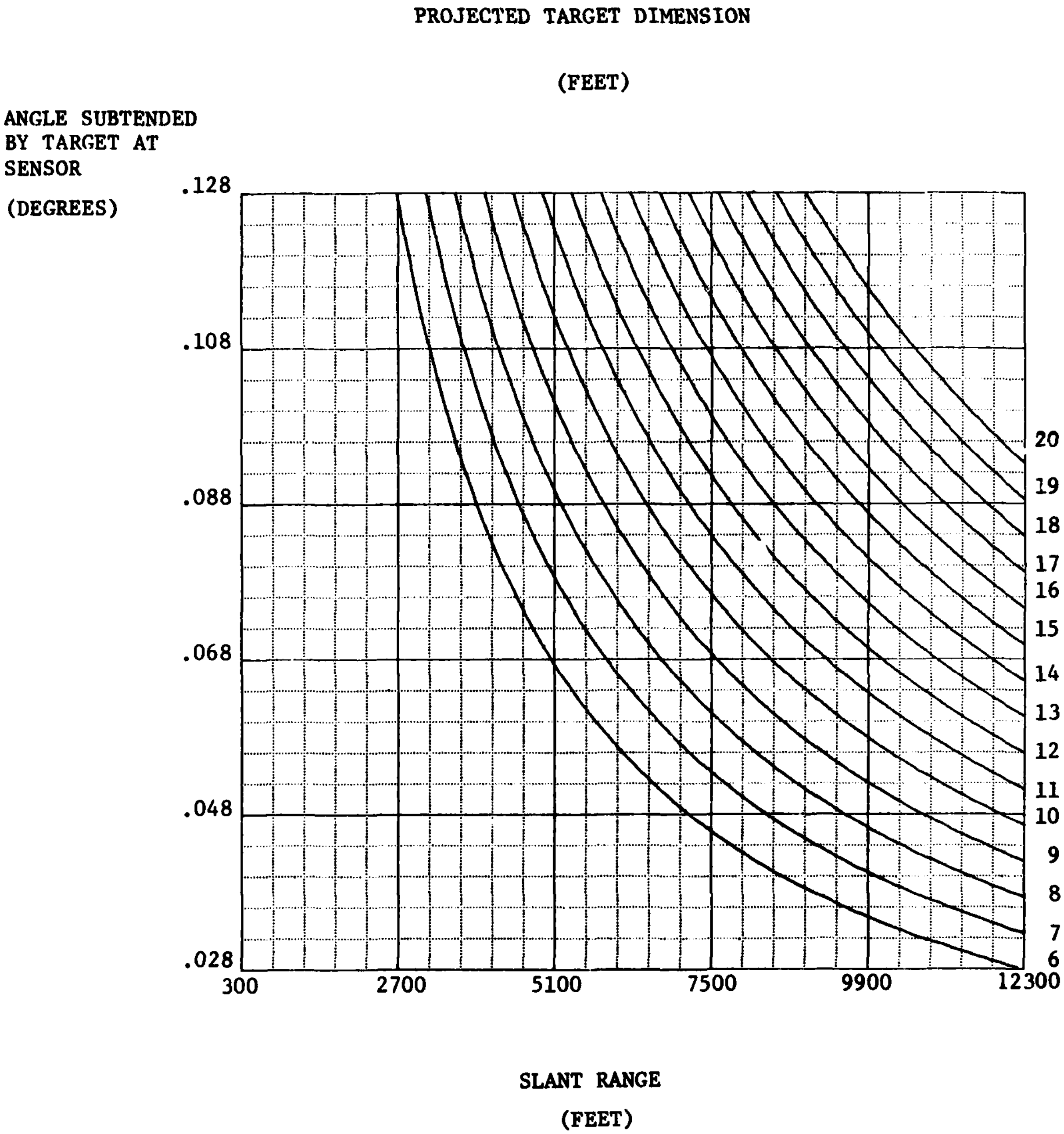

Figure 7. Angle Subtended by Target at Sensor Nomogram

FOV, times the line rate of the sensor. Figure 8A, B, and C are nomograms for each of the common sensor line rates.

Example:	Target Subtense	=	0.070 degrees
	Line Rate	=	875 TV lines
	FOV	=	3 degrees
	Answer:		20 lines (Figure 8B)

The number of TV lines across the target is one of the critical parameters in predicting sensor system performance (the second being the angle subtended by the target on the display). Bailey's model (1970, 1972) requires 10 TV lines to support correct recognition in 90 percet of the trials. Erickson (1978) also reports 10 TV lines being required for 80 to 100 percent correct recognition of a variety of military targets, including ships and land vehicles.

The final three nomograms in this report are all related to the display/observer geometry portrayed in Figure 9. Collectively, they yield the second critical parameter needed to predict system performance, the angle subtended by the displayed target to the observer. (The vertical sensor FOV and display dimension are used for consistency.)

PERCENT OF FOV

This is expressed as the ratio of the angle subtended by the target at the sensor to the total angular FOV of the sensor. Figure 10 provides a nomogram for assisting in this computation. (The angle subtended by the target at the sensor is obtained from Figure 7.)

Example:	Angle Subtended at Sensor	=	.070 degrees
	FOV	=	3 degrees
	Answer:		2.3 percent

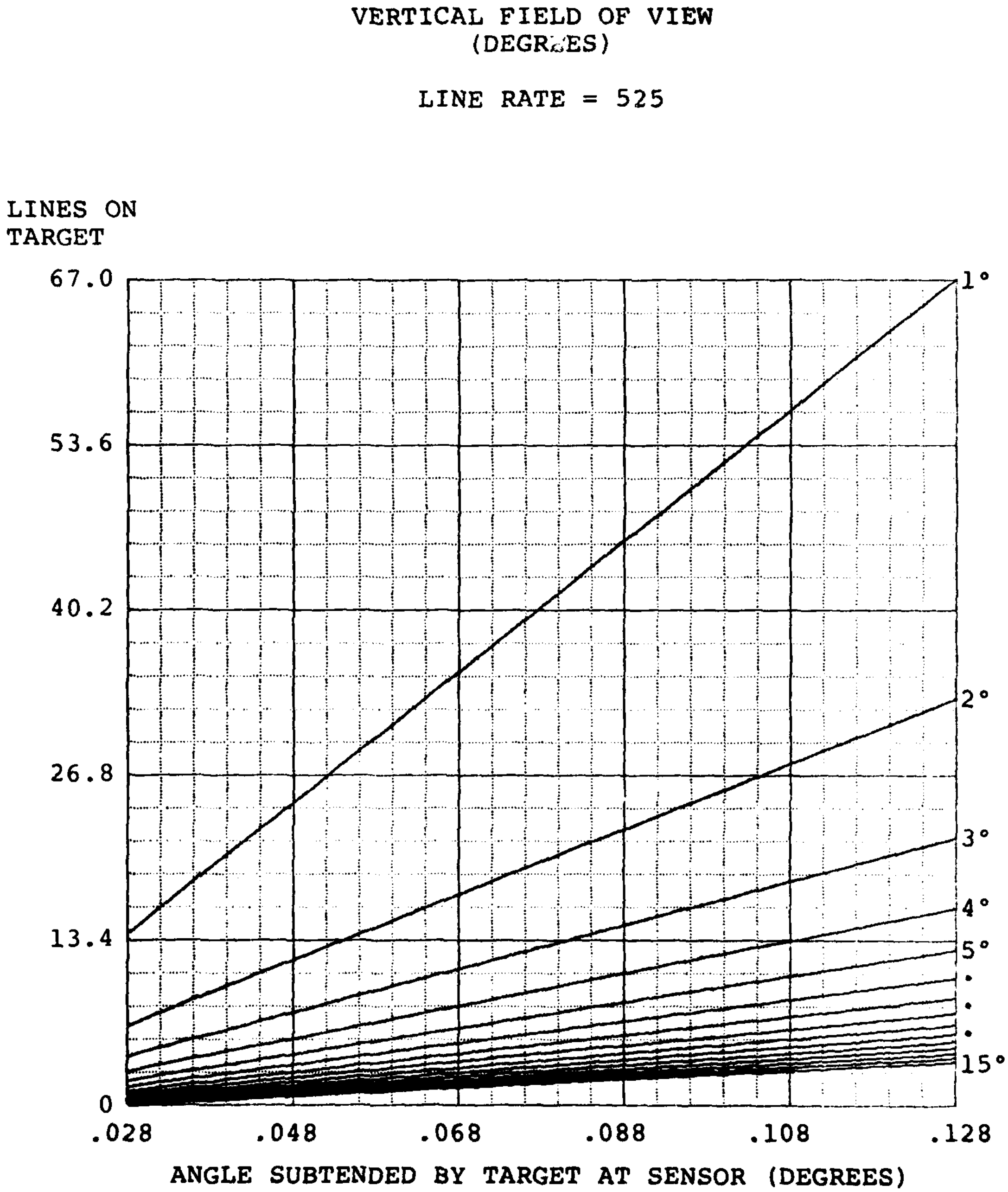

Figure 8A. TV Lines on Target Nomogram--525 Line Rate

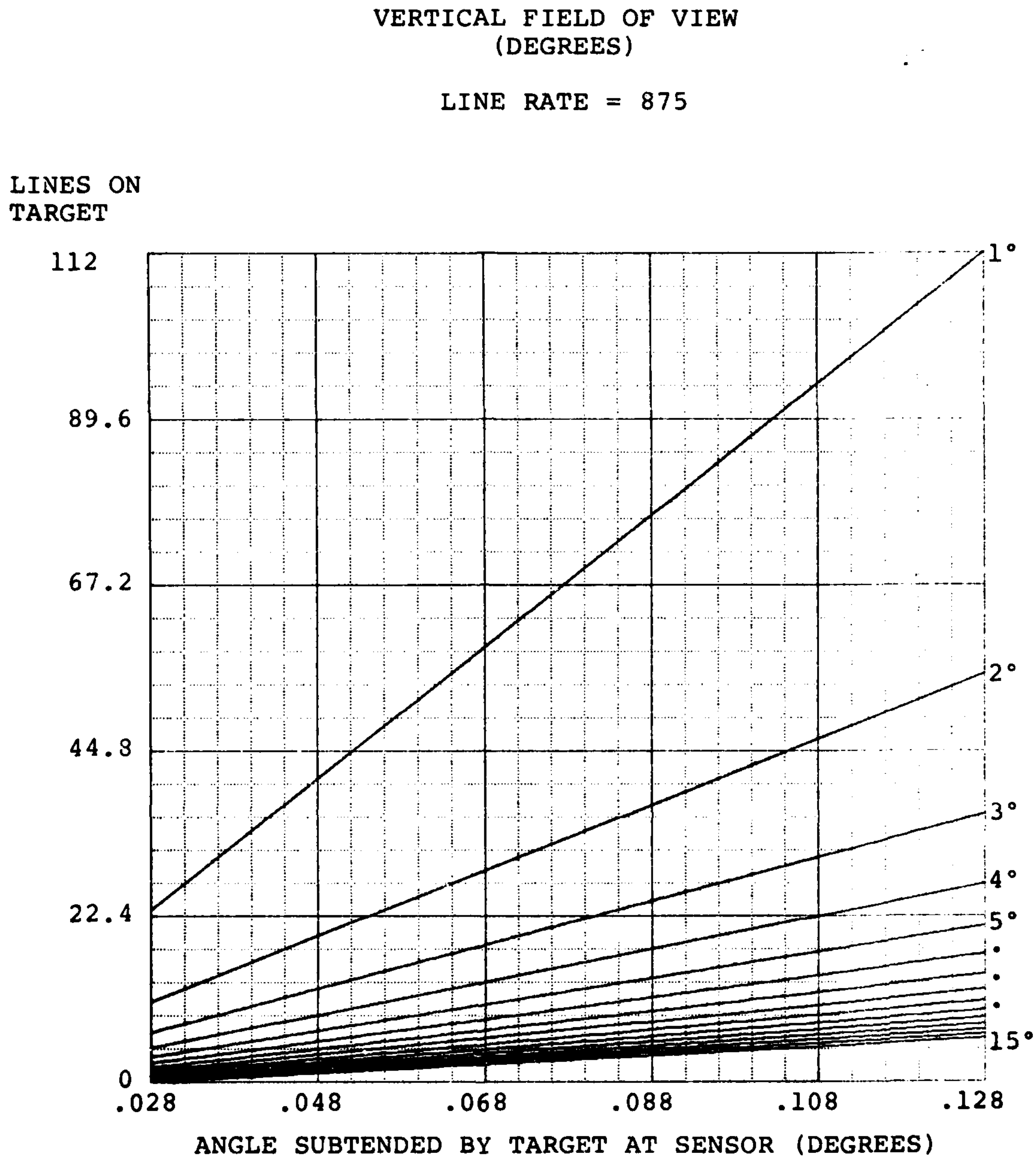

Figure 8B. TV Lines on Target Nomogram--875 Line Rate

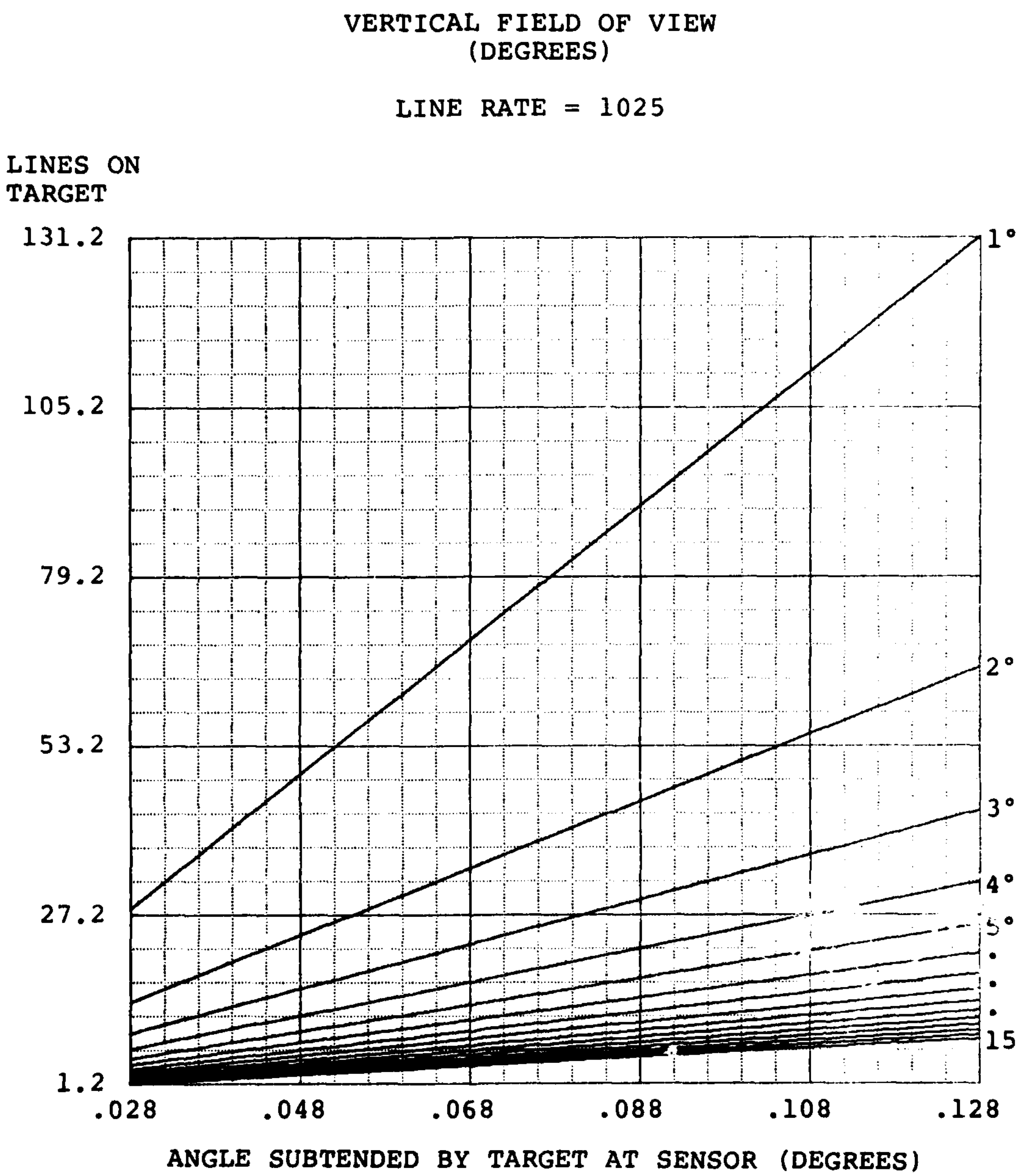

Figure 8C. TV Lines on Target Nomogram--1025 Line Rate

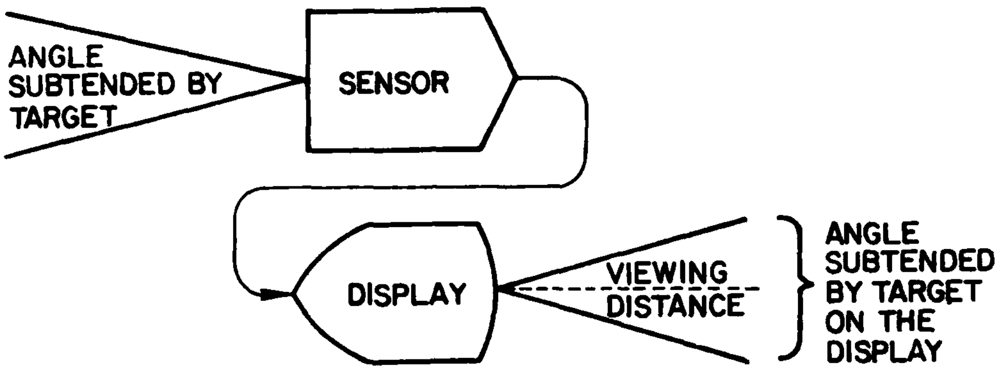

Figure 9. Display/Observer Viewing Geometry

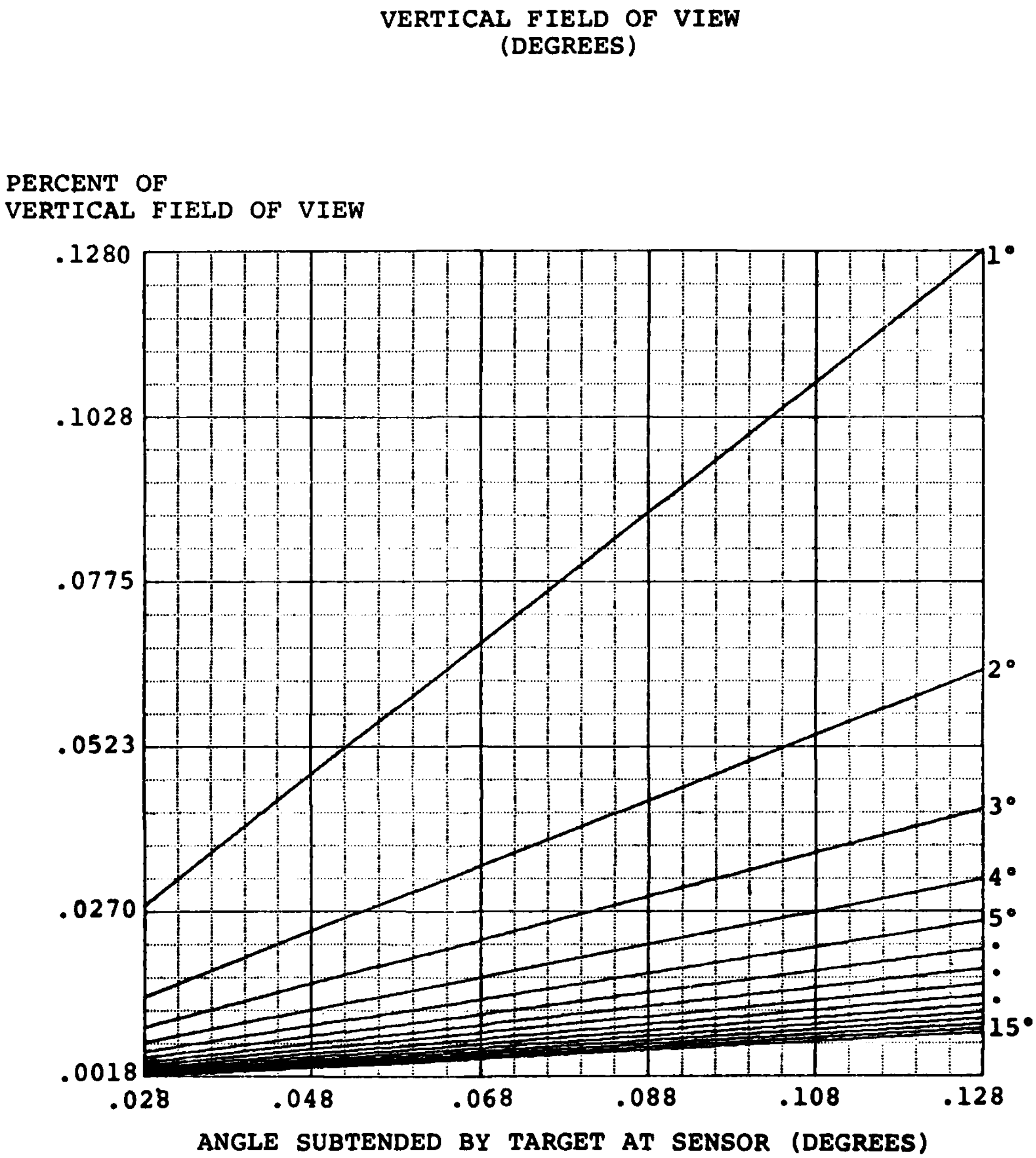

Figure 10. Percent of Vertical FOV Subtended by Target Nomogram

DISPLAY TARGET SIZE

The physical size of the target projected dimension as it is presented on the display. (See Figure 11.)

Example: Percent of FOV = 2.3 percent
Display Dimension = 5.0 inches

Answer: 0.115 inches

SUBTENDED ANGLE ON THE DISPLAY

The angle is subtended by the target's projected dimension within the observer's visual regard. It is a function of the target size on the display and the viewing distance. (See Figure 12.)

Example: Displayed Target Size = 0.115 inches
Viewing Distance = 24 inches

Answer: 16.2 minutes of arc

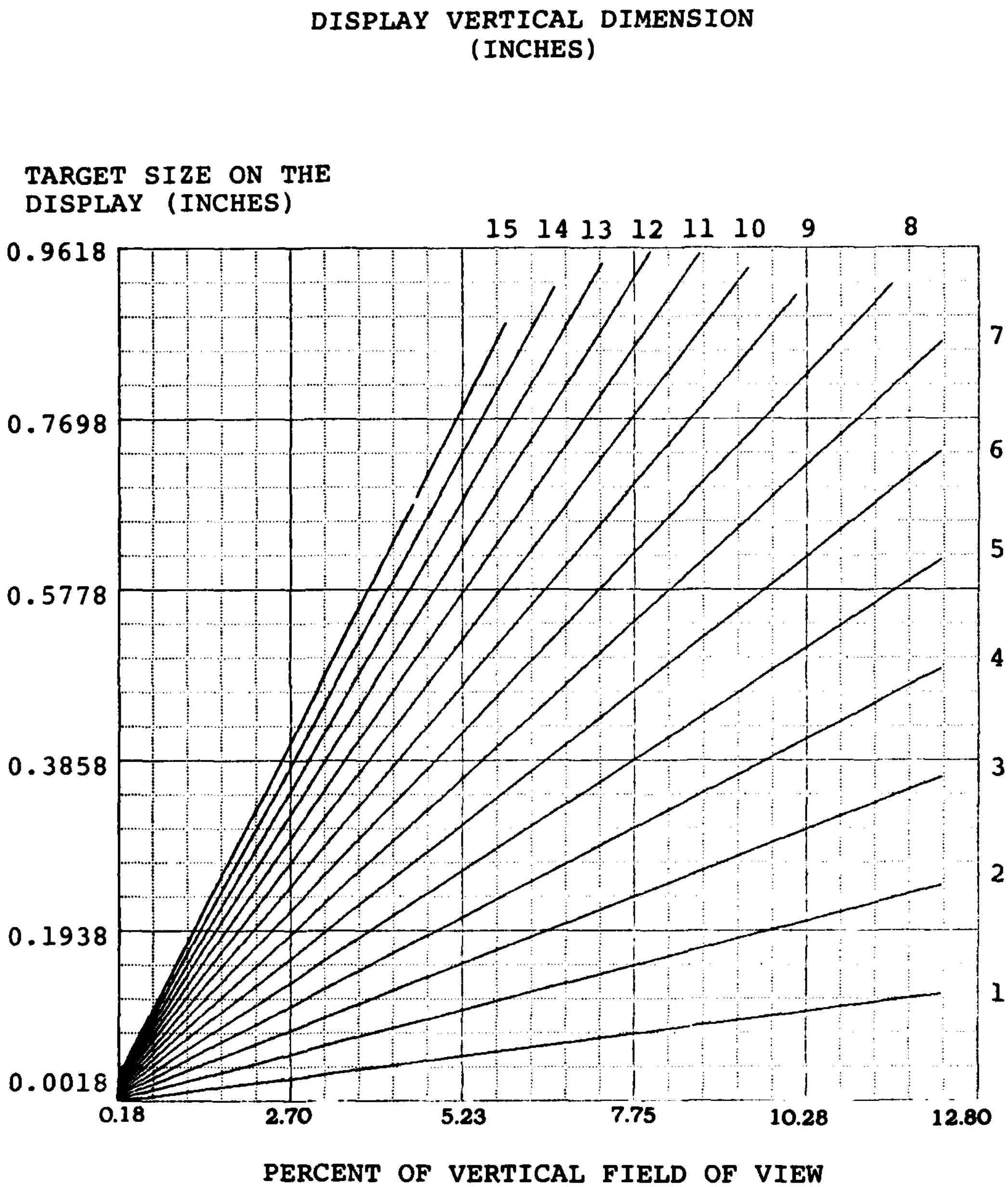

Figure 11. Target Size on the Display Nomogram

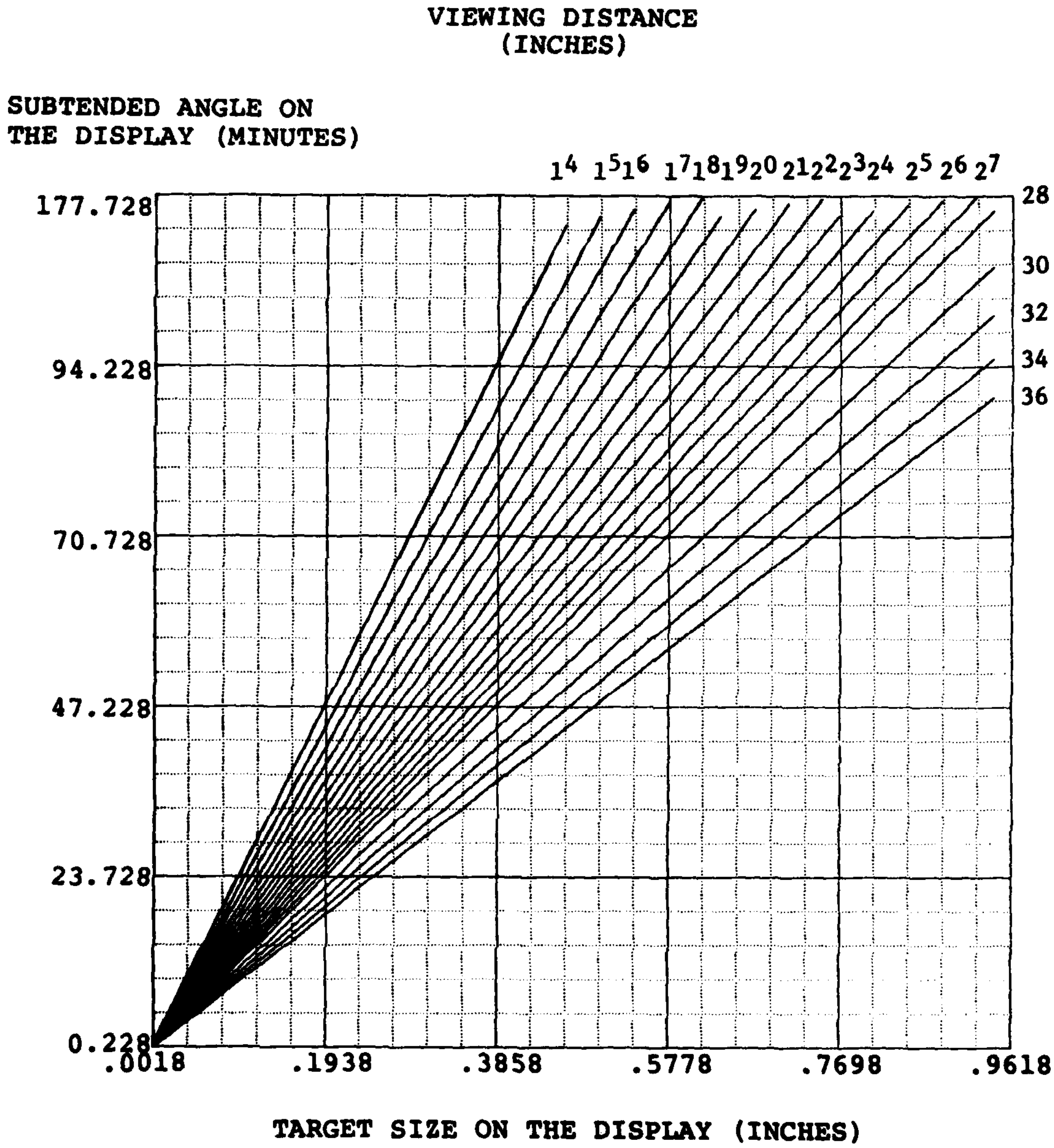

Figure 12. Subtended Angle on the Display Nomogram

CONCLUSIONS

In the example used to illustrate the nomograms, a target with a 10-foot critical dimension was found to be sampled by 20 TV lines at the sensor (*Figure 8B*) and to subtend 16.2 minutes of arc on the display. This would be an intermediate case in terms of the definitions applied by Task (1979). It is not "vision limited" since the displayed target is made up of at least 8 samples and subtends more than 12 minutes of arc (8 times 1.5 minutes limiting visual acuity). It is not "*display limited*" *since, although the displayed target subtends more than* the minimum 12 minutes of arc, it is also composed of more than the 8 samples that Task uses (following Johnson, 1958) as the minimum required for correct recognition. The example also fails to meet Bailey's (1970) requirement of 20 minutes of arc for 90 percent correct recognition. The example would probably support good target recognition performance, perhaps at the 80 percent correct response level, since Erickson and Hemingway's (1970) empiric requirements for at least 10 lines on the target and at least 14 minutes of arc on the display are simultaneously satisfied.

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